GEOMORPHOLOGY

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ABSTRACT

The landforms of the Western Desert are result of the interaction of structure, lithology and climate. The tectonic history of the Stable Shelf, in which the Western Desert is located, has controlled the development of the main landforms and lithology.

The lithologic column of the exposed rocks in the Western Desert consists of limestone, dolomitic limestone, dolomite, sandstone, marl, claystone and phosphorite with rare gypsum. The rocks have been faulted, fractured and exposed in major plateaus after they have influenced by movement of, Hijaz, Najid and Alpine Orogenies.

The paleo-climates have denuded the major plateaus in steps form and caused development of different topographic features, because of their oscillation between tropic, humid and arid climates in repetition forms. The effect of the present arid climate gives rise to mechanical break down of the surface.

The landforms are classified according to relief building forces and geomorphic processes. The genetic units are; structural – denudational, denudational depositional, fluvial, solutional, evaporational and eolian origins.

الجيومورفولوجيـــا

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المستخلص

تكونت الأشكال التضاريسية للصحراء الغربية العراقية اثر تفاعل كل من الحركات البنيوية والصخارية والمناخ. إن لموقع الصحراء الغربية التركيبي ضمن الرصيف القاري المستقر اثر واضح في نوع التضاريس وتركيب ونسجة الصخور المتكشفة فيها. تتمثل الصخور المتكشفة والتي ترسبت في بيئات مختلفة بطبقات من الحجر الجيري والجيري الدولومايتي والدولومايت والحجر الرملي والصخور الطينية والطفل والفوسفورايت وقليل من الجبس.

خضعت الصخور للحركات الأرضية البانية للجبال (الحجازية والنجدية والالبية) حيث أدت هذه الحركات الى تصدع الصخور وتشققها وتكشفها بشكل هضاب واسعة. عانت الهضاب منذ تكشفها من تذبذب مناخي بين الرطب والمداري والقاري أدى الى تقطعها بشكل مدرج ونشوء ظواهر طبوغرافية مختلفة. المناخ الحالي يقود الى تكسر سطح الهضاب ميكانيكيا ونقل الفتات الناعم ريحيا.

تم تقسيم الأشكال التضاريسية في الصحراء الغربية الى وحدات جيومورفولوجية حسب القوى البانية لها والفعاليات الجيومورفولوجية التي أثرت عليها وهذه الوحدات هي: وحدات ذات أصل تركيبي تعروي، وحدات ذات أصل تعروي، وحدات ذات أصل إرسابي، وحدات ذات أصل نهري، وحدات ذات أصل إذابي، وحدات ذات أصل تبخيري ووحدات ذات أصل ريحي.

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INTRODUCTION

Compilation of the present study is based on interpretation of Landsat images and available geomorphological and geological reports, papers and maps. The majority of this data is from GEOSURV◌`s archive.

The Western Desert is a major plateau of a rocky desert. It has got the term desert because of low rainfall and absence of vegetation and thick soil cover. The vast plain of the Western Desert is nearly featureless, rises gradually from east to west to a maximum elevation of 987 m, above sea level. The even surface has thin soil cover especially in the western parts, whereas the exposed carbonates and other rocks form the other part. The main topographic features are some positive features (mesas and buttes), cliffs, canyons, major valleys and depressions. The positive features are represented by Jabel Anah, in the north and Jabel Aneiza, in the west. Long low cliffs trend nearly parallel to each other giving the surface a step-form character. Along the cliffs, mesas and hills are scattered. Several canyons cut the desert from west towards north, northeast and east. The canyons are deep, often steep walled. Major and minor depressions are common in the Western Desert. The major depression are represented by Ga`ara, Nukhaib, Shinana, Al-Birreet and Al-Juthoom as well as Haditha, Al-Habbaniya and Razaza Lakes.

The climate of the deserts is arid with dry summer and cool winter. There are big diurnal changes in temperature, even daily variation of 36^{o} C. The barren land surface becomes intensively heated in daytime and cools during night time, due to high radiation. This process leads to breaking of the surface into blocks and fragments. The mean annual rainfall is very low (75 – 150) mm, increasing westwards, whereas the mean annual evaporation ranges from 3000 – 3500, therefore the remained small quantity of water acts for chemical weathering such as leaching, solution and hydration. For detailed climatic factors, reefer to the General Information.

INFLUENCE OF STRUCTURE, LITHOLOGY AND CLIMATE ON THE DEVELOPMENT OF THE LANDFORMS

The landforms of the desert are result of the interaction between structure, lithology and climate, as indicated by the variable forms of the geomorphological units and features. Each landform reflects the influence of either two of the above mentioned factors or all of them, in its genesis. The three factors are described hereinafter:

- **Structure**

The Western Desert is a gently sloping plain with a gradient of 5 m/Km, towards east and northeast. The dip of the strata is almost horizontal, reaches (1 – 2) degrees. In the western part, around Ga`ara Depression, the beds dip in all directions, while in the eastern and middle parts the beds dip gently northeastwards. The gentle plain reflects the structural position of the Western Desert within the Stable Shelf (Buday and Jassim, 1984).

Rutbah Uplift has played a great role in the historical geomorphology of the Western Desert. According to Buday (1980) and Buday and Jassim (1987) the crest of the uplift had remained as a dry land during Late Cretaceous. Since that time the gradual rise of the uplift has caused increase of the dry land over the whole Western Desert, in form of major plateaus (Fig.1). At the same time the plateaus were dissected into many blocks. The common structural features in the Western Desert are faults, joints, folds, grabens and ring structures.

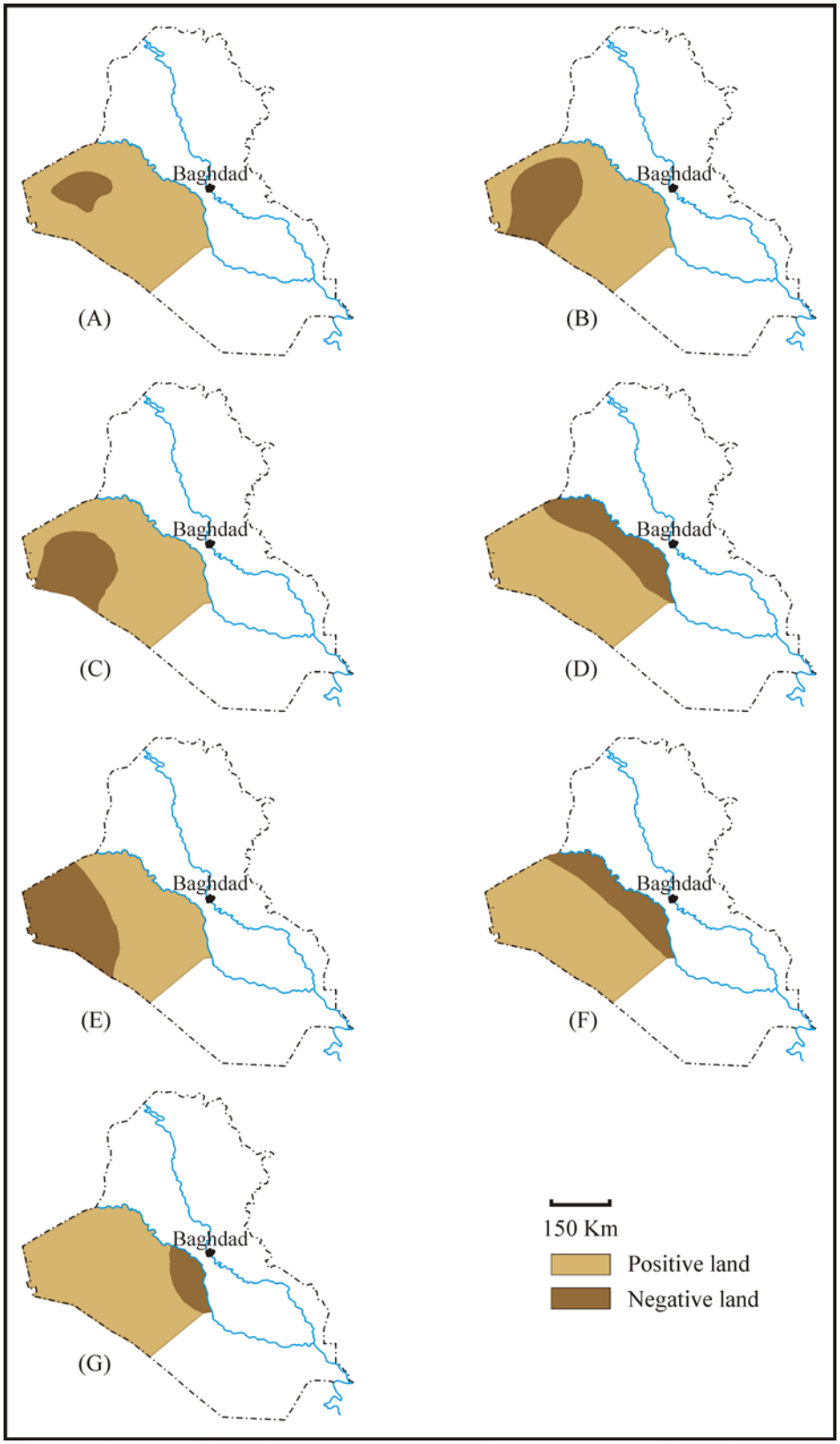

Fig.1: Distribution of positive and negative lands: during Campanian – Maastrichtian (A), Paleocene – Late Miocene (B), late Early Eocene – Late Eocene (C), Oligocene (D), Early Miocene (E), Middle Miocene (F) and Late Miocene – Pliocene (G)

- Faults

Four sets of faults are ascertained in the Western Desert by means of interpretation of Landsat images on basis of drainage, cliffs, distribution of mesas and orientation of depressions. The fault systems are N – S, NW – SE, E – W and NE – SW. The faults are related to very old Orogenies, Kibiran, Hijaz and Najid, which have been rejuvenated during Late Mesozoic and Tertiary by the Alpine Orogeny (Qasir *et al.*, 1992). The faults are thought to be dissected through the basement and the overlying Paleozoic, Mesozoic and Tertiary sedimentary cover (Buday, 1980 and Buday and Haq, 1980).

The relation between drainage and faults is very visible on Landsat images and topographic maps. Most of the major valleys start on the plateau around Rutba vicinity and extend towards north, northeast and east. In each drainage basin of the main valleys, the valleys change their trends at variable angles, between $(45 – 90)^{o}$, these changes coincide with the directions of fault systems (Fig.2).In addition to that the axes of the meanders that have developed along the courses of the valleys coincide with the trend of faults and joints. A third visible example in (Fig.2) is represented by the cliffs developed in Umm Er Radhuma Formation along N – S and E – W faults.

Wadi Swab and Wadi Ratga, which drain the northwestern part of the Western Desert, reflect clear relation between their trend and faults. The lower reaches of the wadies are in N – S direction and reflect their development along weak zone of the same trend. The tributaries of both wadies are also parallel to each other and are controlled by long joints of NW – SE and NE – SW directions. The western tributaries of Wadi Swab are toward NE direction, while the eastern tributaries of Wadi Ratga are toward NW direction. The upper reach of Wadi Swab is dissected by sets of NW – SE joints, resulted in formation of parallel tributaries and rectangular change of the Wadi course (Fig.3).The plateau on Hartha Formation is cut into well oriented mesas due parallel NW – SE trending joints (Fig.4).

Al-Mubarak and Amin (1983) and Qasir *et al.* (1992 and 1993) have identified many faults of the same aforementioned directions, they missed many other faults, which might not be visible due to low displacement or not observed along their traverses, during geological mapping. The Tectonic Map of Iraq (Al-Kadhimi *et al.*, 1996) show also some faults, of the same directions.

- Ring Structures

Many ring structures are developed in the Western Desert. One ring structure is identified within Hussainiyat Formation in the upper reaches of Wadi Ghadaf (Fig.5). The diameter of the feature is about 500 m. Its formation is related to block movements.

Ring like structures are developed on rock beds of Zahra Formation due south of Al-Habbariyah Depression. The rings represent remnants of highly denuded rocks, which are deposited in depressions developed due to volume change of the gypsum of Russ Formation. In the Western parts of the Western Desert, tens of ring structures are developed, they are either of karst origin or hydrocarbon explosion (Hagopian, 1979). The diameters range form few hundred meters to few kilometers. Usually they from depressions on surface of Ratga Plateau.

Tens of circular and oval depressions of different sizes are located in the western part of the Western Desert. They are developed in flat areas, built up by Ratga Formation, locally are called "Faidhah". Some of them are interpreted by geophysical means as ring structures.

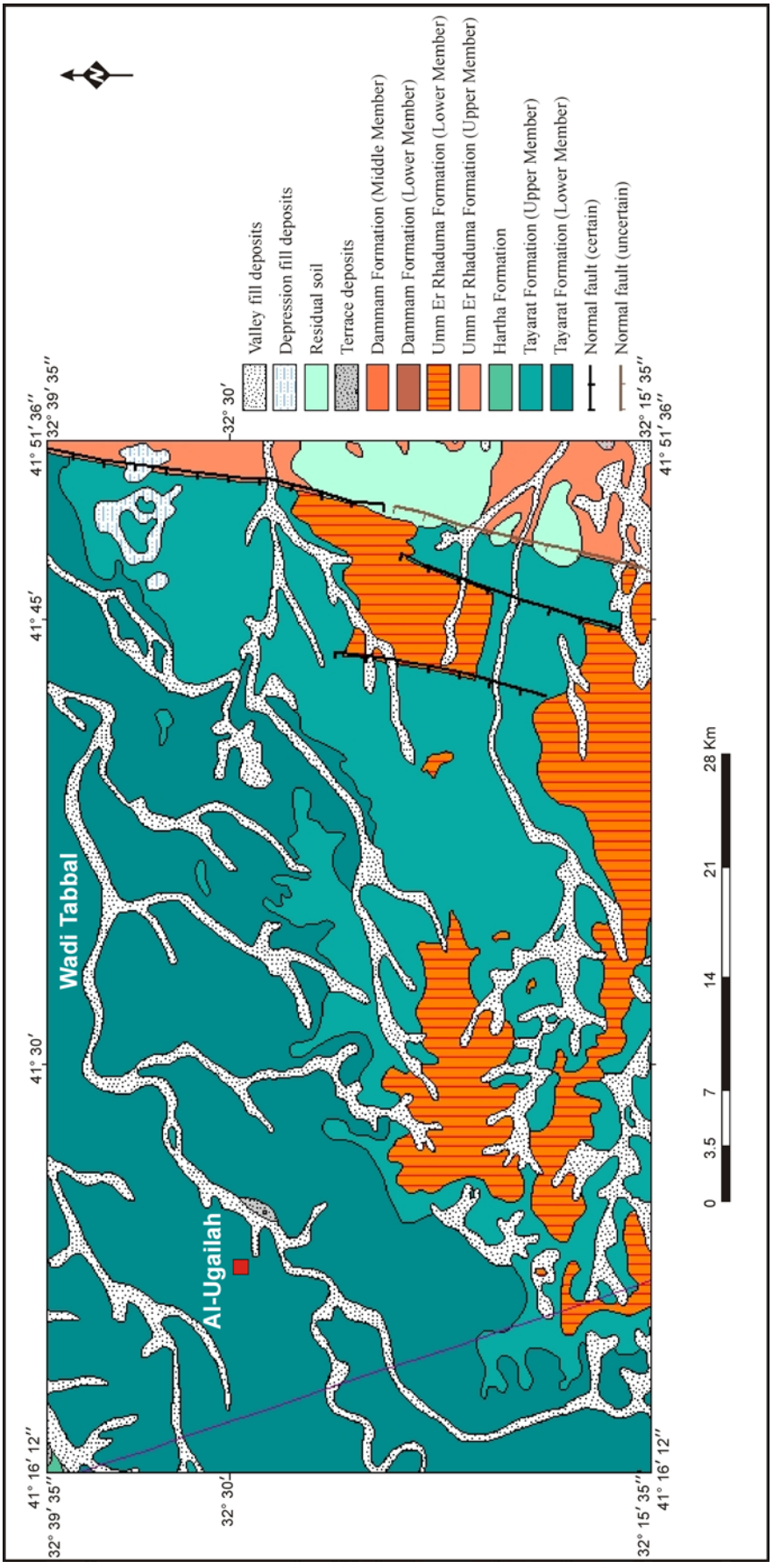

Fig.2: Geological map showing effects of faults on drainage, meanders and cliffs
(after Sissakian and Youhanna, 1995)

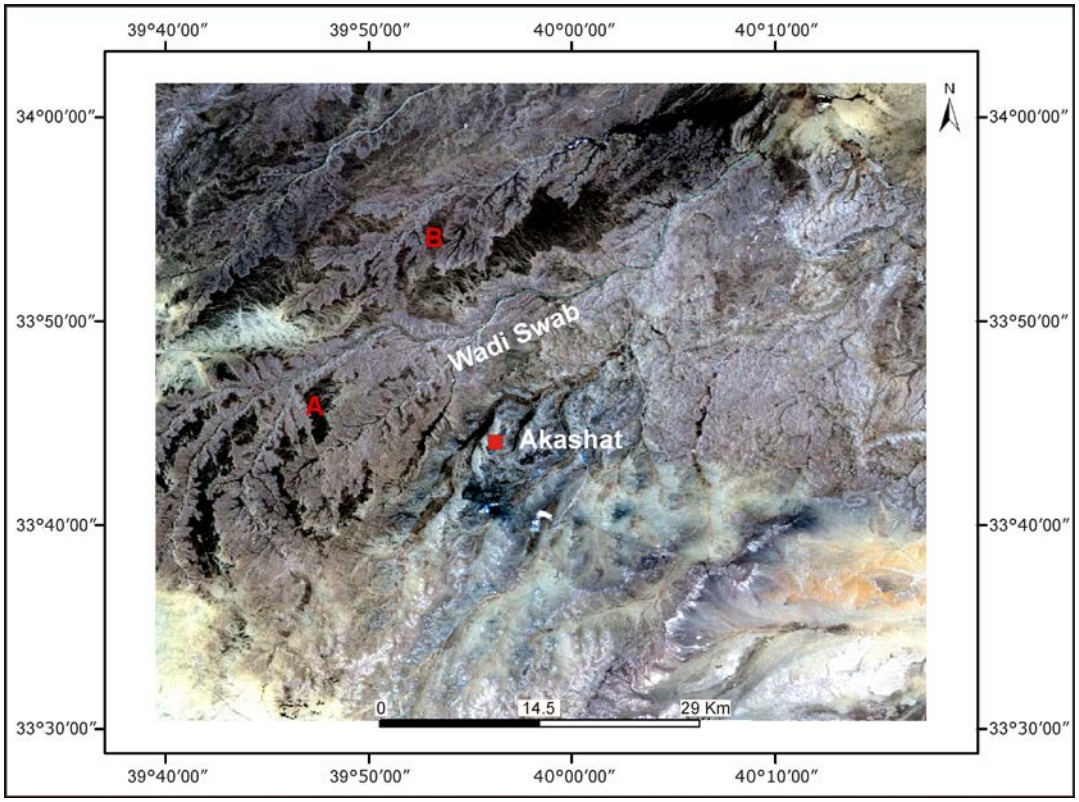

Fig.3: Landsat image showing parallel drainage controlled by NW – SE joints at (A) and fine textured topography at (B)

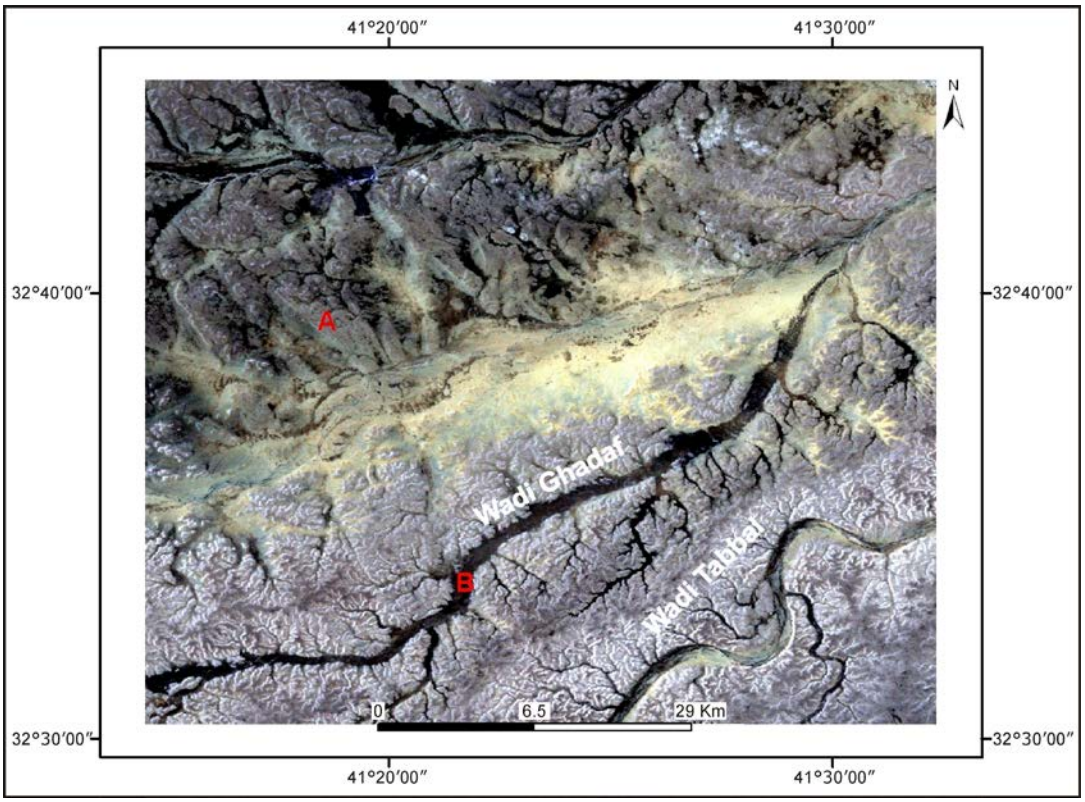

Fig.4: Landsat image showing distribution of mesas along NW – SE faults at (A) and coarse textured badland at (B)

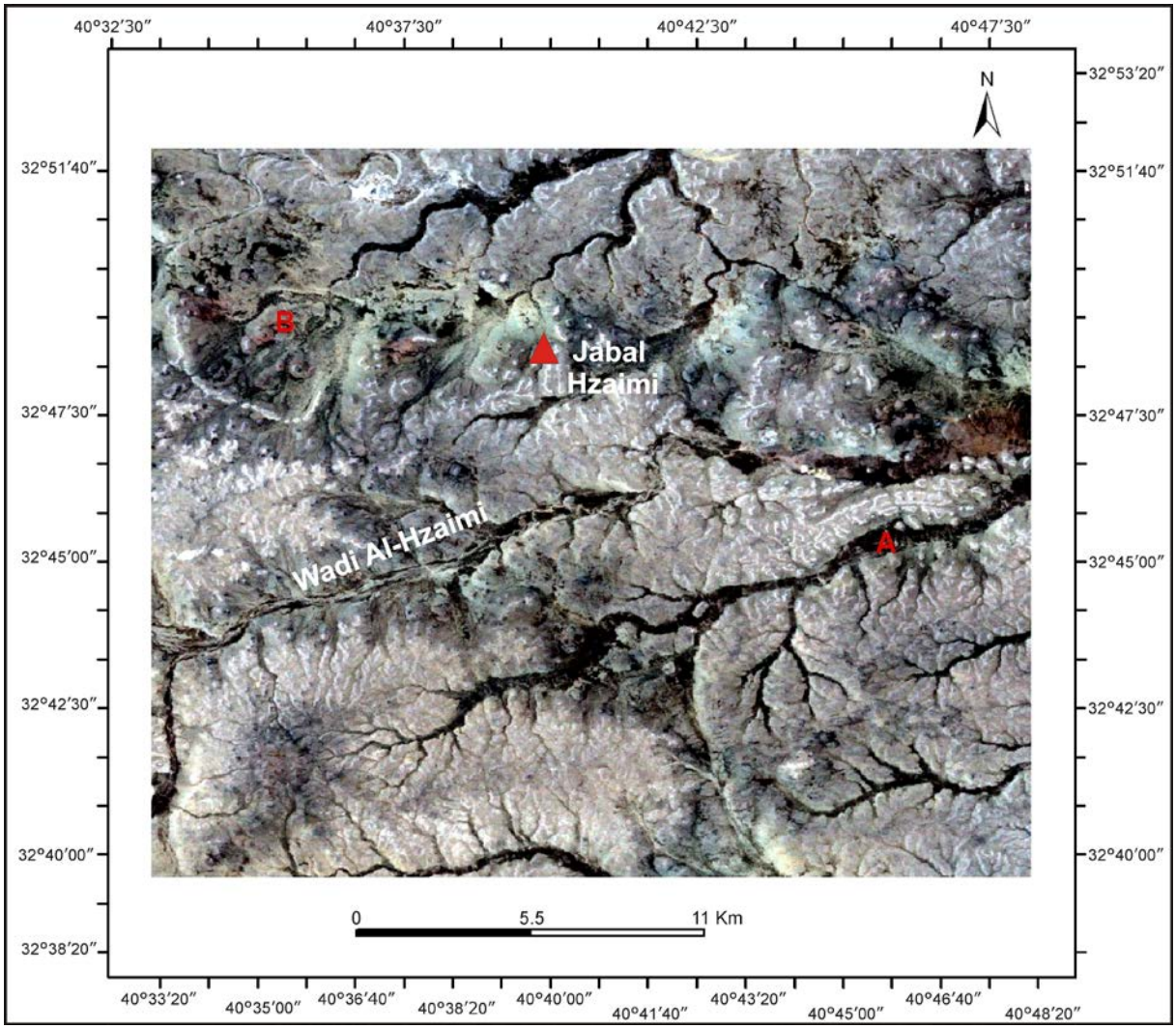

Fig.5: Landsat image showing remnants of fold at (A) and ring structure at (B)

- **Lithology**

The exposed rocks in the Western Desert are of marine and continental origins, represented by limestone, dolomitic limestone, dolomite, sandy limestone, clayey limestone marl, sandstone, and claystone, with rare gypsum and phosphorite.

The primary and secondary characters of the exposed rocks have played a role in the development of different landforms, for example, the hard rocks gave the desert a plateau form. Interbedded rocks of variable hardnesses have accelerated the dissection of the plateau into steps or minor plateaus. The soluble rocks have led in forming of karst units and features. The soft rocks contributed in development of eolian units.

- **Climate**

The surface of the desert is built-up of landforms of different origins; structural – denudational, denudational erosional, fluvial, depositional, karst and eolian. The development of these landforms reflects effects of paleo and recent climates. Climatic changes had started since the beginning of the historical geomorphology of Western Desert in Late Cretaceous, the period during which first dry land was exposed on the surface. During this period, the Western Desert had faced three types of climates; humid, tropic and arid. These three types of

climates were active during Late Cretaceous to Late Pleistocene. During Holocene the climate generally changed to arid and gave rise to intensive mechanical break-down of the surface rocks and consequently development of Sarir, Hamada and eolian features.

GEOMORPHOLOGICAL UNITS

The landforms of the Western Desert are grouped in six major units related to the agents and processes contributing to their development. The units are:

1. Units of Structural – Denudational Origin

Four types of landforms are developed within this type, these are:

- **Plateaus**

Plateaus form onep of the widest landforms of the Western Desert, because of its structural position within the Stable Shelf. The plateaus are surface formed during past geological periods on variable rocks. Some of the plateaus represent contact surfaces between geological formations; others are formed on members within geological formations.

According to Bellen (1959), Kassab(1972 and 1976), Buday(1980), Al-Mubarak and Amin (1983), Al-Bassam *et al.* (1990), Qasir *et al.* (1992 and 1993), and Tamer-Agha (1993) the Ga`ara Uplift had suffered continuous uplifting, faulting and erosion since Maastrichtian till Late Tertiary. The aforementioned processes had exposed old formations on the surface and developed the plateaus on their surfaces. The plateaus form belts of crescentic shape around the trough of Ga`ara Depression from the south. The extension of the plateaus towards north terminates at a line of E – W direction, which runs nearly parallel to the axis of the Ga`ara Depression. The plateaus are listed hereinafter according to their age of exposure to denudation.

- Plateau on Zahra Formation

The plateau represents the youngest plateau level developed in the eastern and northern parts of the Iraqi Western Desert. The plateau is developed in three localities. In the first locality the plateau covers a large area that extends between Wadi Hauran, in the north and Wadi Al-Ubaiyidh, in the south. From west the plateau is bordered by Al-Qusair Fault and Al-Habbariyah Depression. The width of the plateau is about 60 Km, in the south and about 25 Km, in the north. The surface of the plateau is level and dissected by short shallow karst valleys. The middle part of the plateau is rich in small size karst depressions; therefore it is isolated as karst landform. A low cliff separates this plateau from the underlying Nfayil Plateau. In the second locality the plateau covers a wide area in the southern part of the Western Desert (Al-Maaniya Quadrangle, Sheet NI-38-5, scale 1: 250 000). The surface of the plateau is covered by sand sheet. In Al-Birreet area the plateau covers parts of the plateaus on Umm Er Radhuma and Dammam formations. The third locality lies in the northwestern part of the Western Desert, due south of Husaiba (Kherish vicinity), the plateau covers a large area but its surface is highly covered by soil. It is dissected by three canyon like valleys (Akash, Ratga and Mana`i), and separated from the Euphrates Plateau by a continuous cliff of (25 – 35) m height, it is called Al-Kherish Cliff.

- Plateau on Nfayil Formation

Because the formation is built-up of several rock types, therefore several sublevels of plateaus are developed, these are:

*** Plateau on the Clasic Member**

The plateau is developed west of Al-Razaza Lake. Its surface is covered by gypcrete and dissected by dendritic infilled valleys.

*** Plateau on the Carbonate Member**

The plateau is developed in a narrow strip along the right bank of the Euphrates River between Haditha and Al-Ramadi (Sissakian and Hafidh, 1995 and Sissakian *et al*., 1995). It is also developed in patches over a wide areal extends parallel to the Euphrates River from Wadi Al-Mana`i, in the west to the southern part of the Western Desert, in the east. The surface of the plateau is dissected by deranged valleys. The plateau lies over the Plateau on Euphrates Formation. Both levels are separated from each other by a low irregular cliff.

- Plateau on Euphrates Formation

The plateau forms a wide belt (20 – 60) Km between Wadi Al-Mana`i and wadi Thumail. The plateau is formed on the Upper Member of the formation, which consists of limestone and dolostones. The surface of the plateau is covered by soil; therefore it is exposed as patches of variable sizes. The plateau extends also on both sides of Wadi Hauran. The surface of the plateau is covered by residual, fluvial and eolian soils. North of Wadi Al-Khubaz the plateau is dissected into mesas and hills.

- Plateau on Ghar Formation

The plateau is restricted in its extension. It covers two small areas on both sides of Wadi Ratga and Wadi Akash, northwest of Ga`ara Depression. The acreage of the plateau in the first locality is about (20 x 10) Km and about (5 x 10) Km in the second locality. Near the wadis the plateau is dissected in form of structural terraces.

- Plateau on Dammam Formation

The plateau covers the southern part of the Iraqi Western Desert, between Wadi Al-Khar, from the east and the eastern cliffs of Al-Habbariyah and Al-Birreet Depressions, from the west. The surface of the plateau is highly dissected by shallow valleys and depressions, which separated the plateau into two levels, an old level on the surface of the Upper Member of the formation and a young level on the surface of the Lower Member of the formation.

West of wadi Hauran, Dammam Plateau changes laterally into the Plateau on Ratga Formation. This plateau is also formed in two levels. The older level is formed on Damlug Member. The level covers the extreme northwestern part of the Western Desert on both sides of Wadi Al-Walaj. The surface of the plateau is dissected by dense shallow infilled valleys. The younger level is formed on Swab Member. It covers the northern slope of Ga`ara Uplift, in upper reaches of Wadi Swab, Wadi Hirri and Wadi Akash basins. The plateau level is dissected by dendritic valleys.

- Plateau on Umm Er Radhuma Formation

The plateau forms a wide plain between Wadi Tabal and the Iraqi – Saudi Arabian borders. The surface of the plateau is dissected by shallow deranged valleys. Small shallow depressions are scattered on the surface.

In the southern part of the Western Desert, the plateau is preserved as patches due to the development of dense depressions on its surface (Shithatha Qudrangle, sheet N1-38-13, Mahdi and Youkhama (1996) and Al-Birreet Qudrangle, Sheet N1-38-1, Sissakian and Youkanaa (1995) both of scale 1: 250 000). In the western part of the Western Desert, the plateau changes laterally into the Plateau on Akashat Formation, which is equivalent of Umm Er Radhuma Formation. There, the plateau covers a narrow strip along the left side of Wadi Hauran. Its width ranges between (1 – 20) Km. The plateau is of step form, because it is developed on both members (Traifawi and Hirri) of the Akashat Formation and has the form of structural terraces. According to Buday (1980) regression of the sea and uprise of Rutbah Uplift had continued during Early Eocene. At that time, erosion of Umm Er Radhuma Plateau had started.

- Plateau on Tayarat Formation

It represents the oldest plateau in the Western Desert. The plateau had covered part of Rutbah Uplift during Paleocene time, when the top of the uplift was subjected to erosion from one side and the prevailing part of the Western Desert was submerged, from other side (Fig.1.A). According to Bellen *et al.* (1959) and Kassab (1972 and 1976) a break in sedimentation occurred between Maastrichtian and Paleocene.

In the upper reaches of Wadi Tabal, in the middle part of the Western Desert, the plateau is developed on the Upper Member of the Tayarat Formation and is preserved on the divide lines between the valleys, because great part of the formation is forwarded to badland. The plateau surface is rugged and its rims are irregular due to headwords erosion, it forms a very wide flat area between the Ga`ara Depression and the Iraqi – Saudi Arabian borders. Few shallow depressions are scattered on its surface. The plateau forms a wide divide line between the upper reaches of the basins of Wadi Tabal and Wadi Thumail, in the east and the basin of Wadi Hauran, in the west.

- Plateau on Hartha Formation

The plateau covers a wide area in the northern part of Wadi Tabal Quadrangle, Sheet N1-37-16 and Wadi Hauran Quadrangle, sheet N1-37-15, scale 1: 250 000. The surface of the plateau is irregular because of the well bedded rocks of the formation. The plateau changes locally into badland along the main wadis. The back cliff of the plateau suffers backwards erosion as indicated by the mesas on top of Rutbah Plateau. The northern part of the plateau is in contact with the Plateau on Tayarat Formation, because of the Tlaiha – Rutbah Fault, along which the second plateau has been subsided.

- Plateau on Rutbah and Ms`ad formations

The plateau covers a very wide area of H1 Quadrangle, Sheet N1-37-12 (Barwary and Slewa, 1997), Wadi Tabal Quadrangle, sheet N1-37-16 and Wadi Hauran Quadrangle, sheet N1-37-15, scale 1: 250 000. The surface of the plateau is nearly leveled. In Wadi Tabal area the surface is rich in karst depressions and dissected by blind valleys. Northeast of Faidhat Tlaiha, mesas of Euphrates and Zahra formations are scattered on the plateau. The plateau looks over the underlying Mauddud Plateau through a low cliff.

- Plateau on Mauddud Formation

The plateau is narrow and varies in width between (2 – 10) Km. It extends along the old Ramadi – Rutba road due west of Tlaiha Depression, which is located west of Kilo 160. The plateau is dissected by wide shallow wadis, which are either branches of Wadi Hauran or are structural wadis developed along NW – SE lineaments. The plateau looks over the low lying Najmah Plateau, through a cliff of medium height. This back cliff is irregular in extension, because it suffering retreation. The backwards erosion is also responsible for separating of many mesas from the plateau.

- Plateau on Najmah Formation

The plateau is developed on the Upper Member of the formation, which consists of limestone and dolostone. The surface of the plateau is irregular and dissected by wide valleys. The western part of the plateau is truncated by a fault, which brought the plateau in contact with Muhaiwir Plateau.

- Plateau on Muhaiwir Formation

The plateau is developed on the Upper Member of the formation, which consists of dolomite and marly limestone (Barwary and Slewa, 1997). The plateau covers a narrow belt along the right branch of Wadi Hauran. Its surface is cut by NW – SE trending lineaments. Shallow infilled valleys are formed on the northern part of the plateau, whereas the southern part is highly dissected. The plateau is separated from the adjacent Amij Plateau by a high cliff.

- Plateau on Amij Formation

The plateau is developed on the top of the Upper Member of the formation, which consists of dolomitic and marly limestones (Barwary and Slewa, 1997). The surface of the plateau is irregular due to exposure of well bedded rocks. The plateau is densely cut by NW – SE lineaments and covered by Hamada, which is composed of limestone fragments mixed with soil of eolian, residual and fluvial origins. The plateau lies over Hussainiyat Plateau. Both plateaus are separated from each other by a 10 m high cliff.

- Plateau on Hussainiyat Formation

The plateau is developed on the Upper Member of the formation, which consists of dolomitic limestone and limestone (Barwary and Slewa, 1997). The plateau covers a (7 – 15) Km wide belt along the right side of the middle branch of Wadi Hauran. Towards the cliff of the wadi the plateau changes into badland. The surface of the plateau is cut by NW – SE lineaments. The eastern part of the plateau is dissected by deranged valleys. The plateau lies over the Ubaid Plateau and is separated from it by a 30 m high cliff.

- Plateau on Ubaid Formation

The plateau is developed on the top of the formation, which consists of a sequence of dolomite and dolomitic limestone (Barwary and Slewa, 1997).The surface of the plateau is of hilly nature, because it is dissected by dense drainage. The western part of the plateau is cut by parallel lineaments of NW – SE direction, which caused development of wide and short canyons. The back slope of the plateau suffers erosion and toppling, which caused the development of many mesas. The mesas are distributed along the back slope on top of Zor Hauran Formation.

- Plateau on Zor Hauran Formation

The plateau is of step form because of the well bedded character of the formation and presence of hard rocks alternated with soft rocks. The surface of the plateau is slightly dissected by valleys. The plateau is separated from the underlying Mulussa Plateau by a low cliff.

- Plateau on Mulussa Formation

The formation consists of silty sandstone, dolomitic limestone and dolomite (Barwary and Slewa, 1997). The plateau covers a wide area along the southern rim of the Ga`ara Depression. The surface of the plateau is of step form and rugged, because it is dissected by dens drainage system. The drainage is controlled by NW – SE and ENE – WSW joints. Very deep canyons cut the plateau in N – S direction. The plateau is inclined gently southwards and looks over the underlying plateau (Ga`ara Plateau) through a high cliff, attains 120 m.

- Plateau on Ga`ara Formation

The plateau represents the youngest one developed in the western part of the Western Desert. The plateau is exposed in parts of the Ga`ara Depression, especially on both sides of Wadi Mulussa, which dissects the depression from west to east. At the southern part of the depression and along the base of the cliff, the plateau is covered by thick sediments of bajada and talus. In many places of the depression the surface of the plateau is dissected by wide infilled valleys.

▪ **Mesas**

Mesas are very common in the Western Desert. They occur along the cliffs, which separate the plateaus from each other and are developed due to deep erosion along crossed joints that dissect the outer parts of the plateaus. Some of the mesas are far from the cliffs. This indicates that the plateaus, from which the mesas are separated, have widely retreated. The mesas are of variable sizes and shapes. They suffer from erosion and mass wasting (toppling), which changed some of them into buttes or hills.

▪ **Cuestas and Hogbacks**

This type of landforms is well developed in the area south of Al-Nukhaib Depression (Shithatha Quadrangle, sheet N1-38-13, scale 1: 250 000). The features are exposed in ring shapes, representing remnants of domes, which are formed of rocks of Zahra Formation; the features cover an area that reaches about 70 Km in width.

Relics of hogbacks occur in the upper reach of Wadi Tabal and Wadi Thumail basins (Tabal Quadrangle, sheet NI-37-16, scale 1: 250 000). The features reflect short and long folds composed of rocks of Hartha and Tayarat formations (Fig.5).

▪ **Anticlinal Ridges**

This unit is represented by Anah Anticline. The fold is E – W trending along the left bank of the Euphrates River. The anticline is about 7 Km wide and about 75 Km long (Al-Mubarak, 1974). It is an asymmetrical one. Its northern limb is steeper than the southern one; this has caused the development of anticlinal ridges. Both limbs are dissected by parallel valleys. The anticline is dissected by deep canyons (Wadi Khazgah Al-Sharji and Khazgah Al-Gharbi), which drain from south towards the Euphrates river. The crest of the structure is subjected to head wards erosion leading in formation of small peaks.

2. Units of Denudational Origin

Four types of landforms are developed within this type:

▪ **Badlands**

Badland topography is well developed in the Western Desert. Its formation is related to structure (fault and joints), lithology and climate. Percolation of rain water through jointed and faulted permeable rocks during wet seasons causes erosion of the rocks and development of rills, gullies and valleys, density of which depends on spaces between the structural features, rock strength and quantity of water, as erosional agent.

The badlands in the Western Desert are either fine or coarse textured. Best example of coarse textured badland is formed on rocks of the Lower Member of Tayarat Formation in the upper reach of Wadi Tabal and Wadi Thumail Basins (Wadi Tabal Quadrangle, sheet N1-37-6, scale 1: 250 000 and Fig.5).

Badland is also developed along lower reach of Wadi Hauran, down stream of the junction of Wadi Hussainiyat and Wadi Amij. The formation of the badland is greatly related to NE – SW and NW – SE joints. The divide lines between the valleys are cut in form of hills. The badland is developed on rocks of Ubaid, Hussainiyat and Euphrates formations. On both sides of the branches of the upper reach of Wadi Swab narrow belts of fine textured badlands are formed (Fig.4).

▪ **Pediments**

Erosional and depositional pediments are identified on landsat images along the base of Anah Anticline. The erosional pediments are formed on bedrocks of the Euphrates Formation, while the depositional pediments are formed on relics of bajada deposits. The pediments on the northern side of the anticline are wider than those on the southern side. Surface of the pediments is highly dissected by valleys.

Along the base of the northern rim of Ga`ara Depression a wide belt of depositional pediment is developed. The surface of the pediment is smooth. Small sized erosional and depositional pediments are also developed at the base of the cliffs like Al-Kheish, Shinana, Al-Jithoom and Al-Birret.

▪ **Hills (Buttes)**

Hills are common in the Western Desert. They occur in scattered form on surface of all plateaus. The hills are relics of mesas which are reduced in size and changed in shape by head wards erosion and toppling. Many hills within Ratga Formation cover a large area north of Ga`ara Depression. The hills are well oriented, reflecting erosion along crossed joints. In H_1 area hills within Ghar Formation are common on surface of the plateau on Euphrates Formation. Many well known hills are developed in different parts within different formations due to aforementioned reasons, among them are Al-Ramameen (south of Anah), Al-Umghar (south of Kilo 160), Garat Al-Shutub (west of Karbala), Damloog (west of Akashat), Nhaidain (southwest of Rutbah) and Tlool Al-Zurrug (west of Al-Birreet) (Fig.1, of the PREFACE).

▪ **Depressions**

Large size depressions are common in the Western Desert. The main depressions are Ga`ara, Al-Habbariya, Shinana and Al-Birreet. The most important element in development of the depressions is the existence of faults along which denudation is very effective.

Ga`ara Depression is the largest one. Its dimension is about (30 x 55) Km. The depression is oval shape, extends E – W. It is surrounded by cliffs of variable heights. The cliffs in the south reach up to 120 m in height, whereas in the north and east are much lower ranging (15 – 55) m. The cliffs are still suffering retreation due to head-ward erosion. Rocks of the oldest formation (Ga`ara Formation) are exposed in patches in the floor of the depression. The depression is filled by valley fill, cones, fans and calcrete. The depression is part of the Ga`ara Uplift, which has suffered continuous denudation since Cretaceous – Paleocene break.

In the end of Paleocene the morphology of the depression seems to have started to be formed. During Late Pleistocene the floor of the depression was few meters higher than its present level, as indicated by the mesas of calcrete and alluvial fan levels.

Al-Habbariyah, Shinana and Al-Birreet Depressions are developed in the southeastern part of the Western Desert. They are younger in age than the Ga`ara Depression, as evidenced by the exposures of Zahra formation on their both sides. The depressions were formed by denudation along N – S trending faults and enlarged by retreation of their cliffs. The depressions are (35 x 70, 8 x 50 and 7 x 40) Km in dimension, respectively. They are filled by fine and coarse sediments. The fine sediments were laid down by the wadis, which cross the depressions, whereas the coarse materials are gravels of alluvial fans, which extend along the western side of the depressions. The depressions are surrounded by cliffs in the east are of medium height, while those in the west are lower.

3. Units of Fluvial Origin

Six landforms are developed within this type:

▪ **Terraces**

River terraces are developed along the Euphrates River and some of the main wadis. Tyracek (1981) studied the terraces of the Euphrates River in seven localities. He identified eleven terrace levels and grouped them in five groups. The groups are (233 – 218, 216 – 205, 205 – 200, 185 and 175) m a.s.l. The first three levels are missing in Anah area because of Anah anticline. In Heet area there are four terraces stages; (100, 70, 50 and 20) m above Euphrates river level (Hamza, 1975). The materials of the terraces are composed of loose and cemented, pebbles of chert and carbonates with rare, igneous and metamorphic rocks. The pebbles are of variable shapes and range in size from gravel to cobble.

Tyracek and Youbert (1975) have mapped two terrace levels along wadi Hauran. The highest level is in H_1; it covers large area and is 50 m above valley floor. The second level is

7 m above the floor of the wadi. The pebbles of the terrace are composed of chert, carbonates and sandstones with conspicuous amount of geodes. Al-Mubark and Amin (1983) termed the deposits of the highest level as Hauran Gravel and mapped them as old flood plain. The present author described the gravel on both sides of Wadi Hauran (the highest level) as alluvial fan deposits.

Terraces are also formed in Ga`ara Depression, restricted to the main ephemeral streams of Wadi Mulussa and Wadi Shaib Al-Oja. Tamer-Agha (1993) has mapped three terrace levels in the depression. The highest level is about 20m above the alluvial plain. The same author has described the active alluvium to represents the lowest level. In Abu Jir and Kubaisa vicinities, valleys have their own terraces, covering both banks. The pebbles are mainly of carbonates and silicates, their sizes range from (1 – 15) m, with different shapes. The thinskness is also variable, but usually (0.5 – 3) m (Sissakian *et al.*, 1995).

The dating of terraces is not accurate, because of the absence of paleontological and archeological data or other relevant methods. Tyracek (1981) gave approximate age to the terraces of the Euphrates River on the basis of their altitudes. He expected the highest level (90 m a.w.l.) to be Early Pleistocene age, the second level (60 m a.w.l.) of late Early Pleistocene age, the third level(35 m a.w.l.) of Middle Pleistocene age and the lowest level of Late Pleistocene.

- **Alluvial Fans**

Alluvial fan topography is common in the Western Desert. The fans were collisced together in form of bajada. The surface of the bajadas shows local breaks in slope indicating stages of fans. The stages are consequence of climatic changes.

A very large belt of bajada is developed west of Al-Habbariyah, Shinana and Al-Birreet Depressions. It extends from Wadi Ghadaf, in the north to Iraqi – Saudia Arabian borders, in the south [sheets N1-38-13 & N1-37-16 (Hassan and Hassan, 1994), N1-38-1 and N1-37-4 (Hafidh and Youkhanna, 1992), N1-37-3 and N1-32-4 (Hafidh, and Youkhanna, 1992) and NH-38-5, scale 1:250 000 (Barwary and Slewa, 1996)]. The bajada is laid down by the wadies Thumail, Tabbal, Al-Ubaiydh, Hamir and Ar`ar. The bajada consists of poorly sorted clastic sediments, usually gravels with subordinate amount of sand. The pebbles consist of limestone with less amount of chert and are poorly cemented.

In Al-Habbariya Depression, three stages of alluvial fans are developed (Fig.6). The stages differ from each other in degree of dissection. The higher two stages are highly dissected and separated from each other by a cliff. The two stages are probably of Pleistocene age. The third stage (youngest) is of smooth surface and might be of Early Holocene age.

A belt of bajada (1 – 6 Km wide) is formed along the base of the southern rim of the Ga`ara Depression, because many large wadis, like Al-Oja, Ujrumiyat, drain in the depression from the south. Almost all of them are still active.

- **Scree Slopes**

Scree slopes are formed along the base of most of cliffs in the Western Desert. The slopes are gentle to steep in inclination. Degree of inclination depends on type of their materials. Slopes formed of fine material are gentle, while large fragments tend to accumulate in slopes exceeding 30º.

Along the base of the cliffs of Ga`ara Depression, a (1 – 2) Km wide scree slope is described by Tamer-Agha (1993). The materials of the scree slopes are the result of denudation processes, where disintegrated rocks fall down slopes by gravity and rain water. The materials consist of mixture of fragments and blocks of limestone and sandstone,

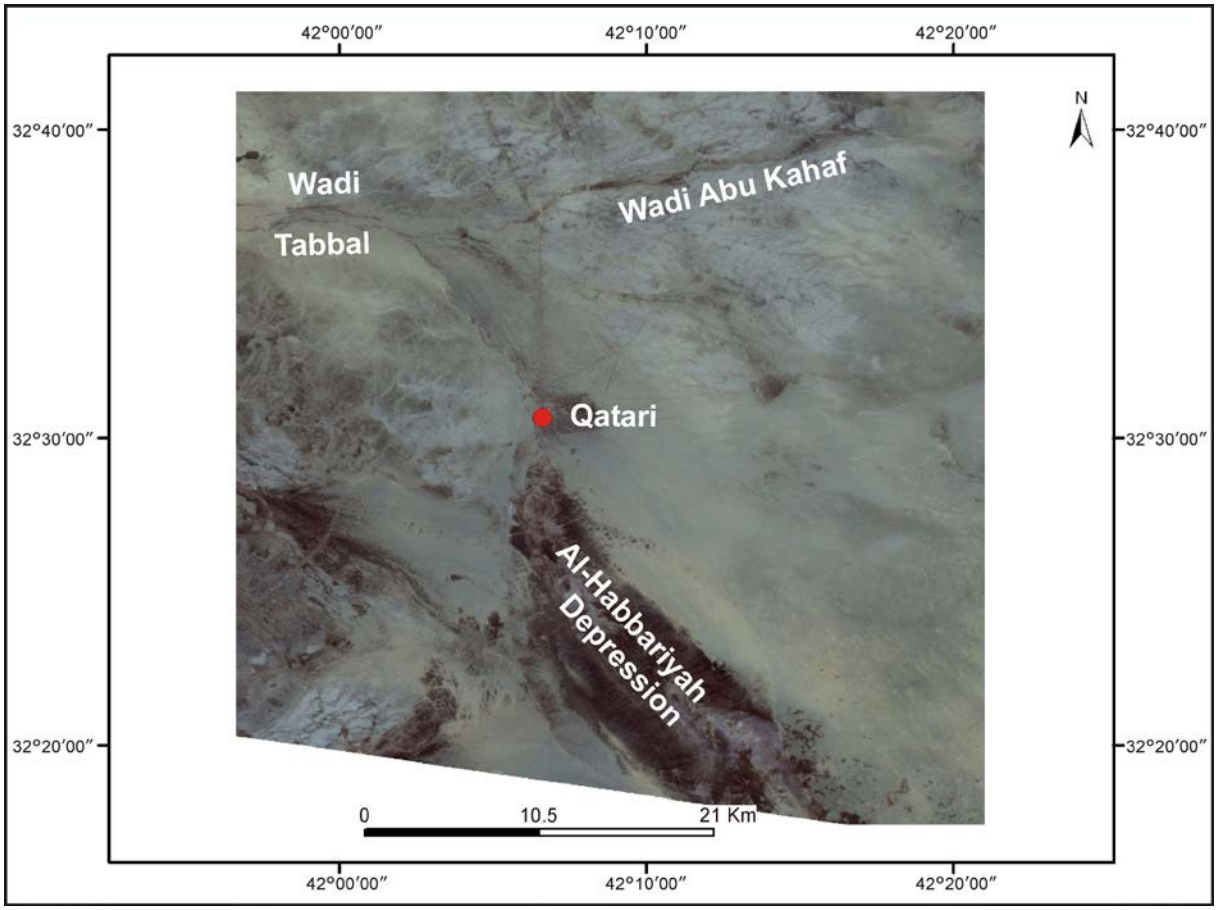

Fig.6: Alluvial fan stages of Al-Habbariyah Depression

moderately to well cemented by calcareous and sandy cement. Another example is Al-Kherish cliff, where large rock blocks are toppled down. Usually the scree slopes are partly covered by eolian sand, like in Al-Kherish and Qasir Al-Khabaz vicinities.

- **Infilled Valleys**

Infilled valleys are represented by main wadies and their tributaries like; Al-Walaj, Swab, Akash, Hirri, Mulussa, Hauran, Hussainiyat, Amij, Thumail, Tabbal, Aghari, Ubaiyidh, Ghadaf, Hamir and Ar`ar. The drainage system of the tributaries of these wadis is dendritic with some local change into rectangular. The wadis trend almost parallel to each other, because of the main slope direction, towards the north and northeast.

The infilling of the wadis are either fine (loam) or coarse (gravel and sand). The thickness is variable. According to Al-Bassam *et al*. (1990) the thickness in Ga`ara area ranges from few centimeters to 40 m in wadi Al-Ubaiyidh reaches up to 70 m in thickness (Al-Mubarak and Amin, 1983).

- **Infilled Depressions**

Infilled depressions are common on surfaces of all plateaus. They are of variable sizes, ranging from few square meters up to few hundred square kilometers. The depressions vary also in age. They have started to develop since Late Cetaceous. The depressions are either erosional or solutional in origin. The infilling materials of the depressions consist generally of fluvial materials with subordinate influence of eolian activity. The old depressions are

infilled by collapsed material, from the surrounding rims, consists of rock fragments and blocks mixed with soil.

- **Flood Plains**

Flood plains are restricted to the Euphrates River and are subjected to periodic flood. They form flat plains, cultivated and composed of laminae of variable thicknesses of sand, silt and clay. The main valleys have developed their own flood plains, which have the same composition. The thickness varies from less than one meter to few meters.

4. Units of Evaporation Origin

The units represent products of advanced chemical weathering on surface. They are developed under climatic conditions marked by alternating wet and dry seasons. During the dry season, capillary action brings to the surface the solutions formed during the wet season and concentrate them as gypcrete, calcrete or silcrete, depending on the type of the material and chemistry of water. These features cause induration of the surface layer and weathering products. Depending on the stratigraphic position, the units are more likely of Pleistocene – Holocene age.

- **Calcrete**

Calcrete is locally preserved in the Western Desert. It consists of heterogeneous rock fragments of variable composition cemented by silty, sandy calcareous materials. According to Tamer-Agha (1993) in wadies of Ga`ara Depression, like Nijili, Luwaiziyyah, Shaib Al-Oja, Soofi and Um Idiyyah, a fairly uniform blanket of calcrete ranges in thickness between (1 – 4) m is developed. At Marbat AL-Hissan a 5 m thick bed of calcrete is formed. The bed is compacted and inclined between 5 and 10 degrees. The inclination might indicate incision of the depression floor directly after the formation of the calcrete.

- **Gypcrete**

Gypcrete is well developed on surface of the plateaus on Euphrates and Nfayil formations, west of Al-Habbaniyah and Razaza Lakes (Al-Mehaidi *et al.,* 1975) the gypcrete is locally massive and fairly to well compacted. The gypcrete reaches up to few meters in thickness, locally it is covered by gravel lag indicating remnant of very old terraces.

- **Sabkha**

Sabkha is well developed in Hit area along Abu Jir Fault Zone and Razaza and Habbaniyah Lakes, along their banks. The sources of the brine in the former locality are springs water and in the latter is the lake's water.

5. Unit of Solution Origin

The basic factor of karst formation in the Western Desert is the presence of soluble rocks (limestone and dolomitic limestone) associated with concentrated water circulation along highly permeable zones (joints, fractures, faults or bedding planes). Karst features are developed on surfaces of most of the plateaus. They are rounded, oval or elongated shapes and developed individually or in colonies (Fig.7). Some of them are connected with each other forming karst valley. They are generally oriented reflecting the role of structural features in their development.

Qasir *et al.* (1992) described karst forms of variable shapes and dimensions on surfaces of the plateaus on Zor Hauran, Ubaid, Hussainiyat and Amij formations. Qasir *et al.* (1993)

mentioned that the sinkholes on Ubaid Plateau extend from the junction of Wadi Hauran and Wadi Al-Hussainiya, in the east to Al-Hussainiya Iron quarries, in the west.

Karst features are also developed on surfaces of Damam, Umm Er Radhuma and Euphrates formations. Al-Mubarak and Amin (1983) refered the karst development to solution of gypsum and salts of Russ Formation, which underlies the Dammam Formation. Karst depressions cover a very wide area on both sides of Wadi Hauran. In vicinity of Kilo 160, dense small size infilled depressions were formed on surfaces of the plateaus on Ms`ad, Euphrates and Zahra formations. In the area north of the Wadi Hauran the karst unit extends over a wide area around H_1 pump station. Sissakian *et al.* (1986) described tens of sinkholes in Anah – Haditha – Hit vicinity. They are developed on the top of the Euphrates Plateau with, circular and oval shapes, with diameters of (1 – 100) m and depths of (1 – 35) m. Ma`ala *et al.* (1999) described many karst forms in Ashwa vicinity on top of the Ms`ad Plateau. Hamza (1997) and Sissakian and Ibrahim (2005) delineated all karstified areas in the Western Desert.

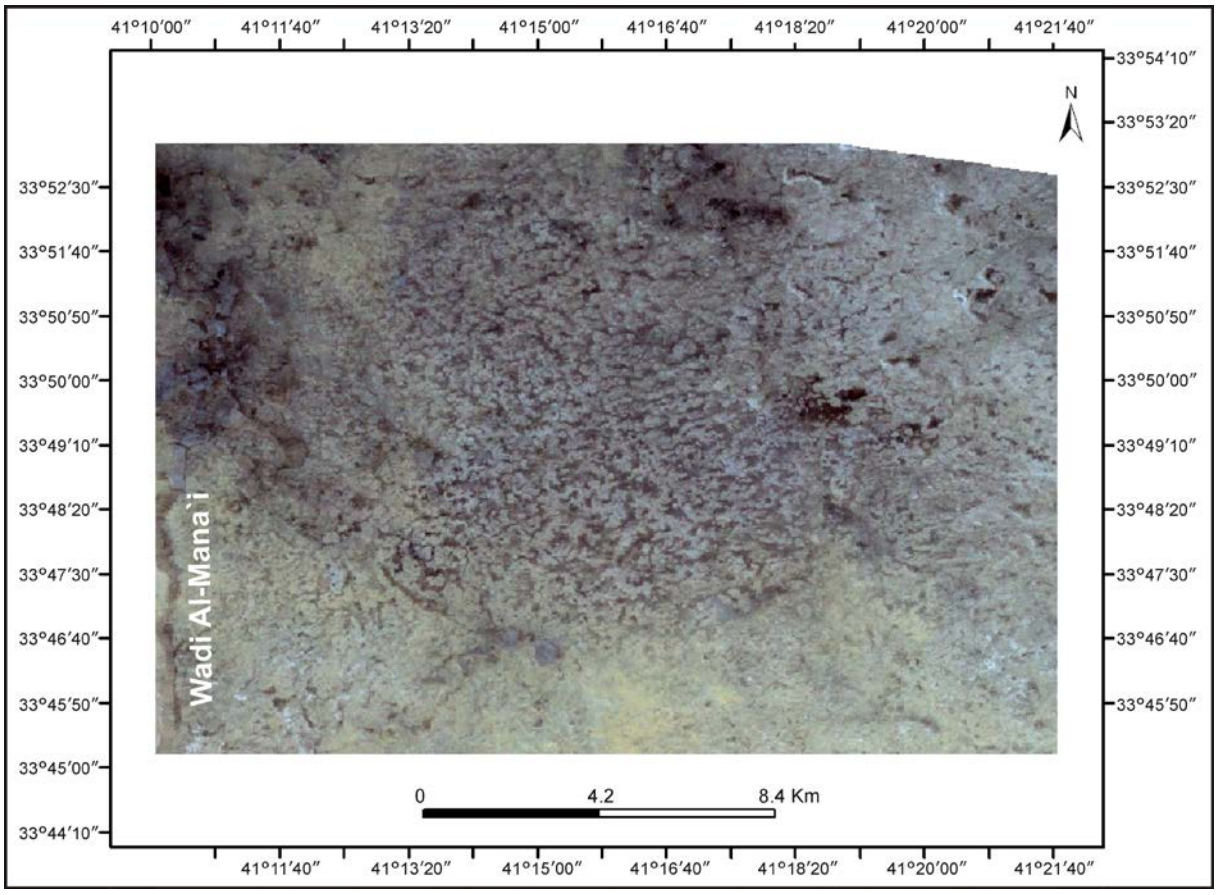

Fig.7: Karst topography (west of H_1)

6. Units of Eolian Origin

Locally, due to eolian activity different forms are developed and are represented by small fields of sand dunes, sand sheets and Nabkhas. In the eastern part of Ga`ara Depression the three types of eolian landforms are developed, composed of quartz sand (Tamer-Agha, 1993). South of Razaza Lake low sand dunes (maximum height 2 m) are scattered in a strip of NW – SE direction, indicating the main trend of wind. Fields of sand sheet and sand dunes are

developed in three localities; on both sides of Wadi Al-Mana`i, Al-Awaj Depression and Qasir Amij Depression. The sheets composed of grains of quartz and carbonate. Scattered Nabkha covers a wide belt in Al-Birreet area along Iraqi – Saudi Arabian borders. Sand sheets are also developed in the western parts of the Western Desert, with height of (0.2 – 1) m. In shallow valleys and depressions, Nabkha is very well developed, with height of (10 – 50) cm.

CONCLUSIONS

- The Western Desert is a major plateau of rocky desert.
- The main topographic features are mesas, buttes, cliffs, canyons, wadis, depressions and sinkholes.
- Rutbah Uplift has played a great role in the historical geomorphology of the Western Desert. Since Late Cretaceous the crest remained as dry land, starting to develop plateaus on different formations.
- The major changes in direction of valleys coincide, mainly with major faults.
- Six major geomorphological units are developed, these are: Structural – Denudational, Denudational, Fluvial, Evaporation, Solution and Eolian.
- The number of the developed plateaus on the top of different formations is 18, the younger one being developed on the top of the Ga`ara Formation.

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